Electron-ion Temperature Relaxation in Dense Plasmas

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In a high-temperature hydrogen plasma, such as in inertial confinement fusion (ICF) or in the center of stars, the ions undergo fusion reactions to produce energetic helium nuclei (alpha particles). The alpha particles then share their energy with the plasma ions and electrons via Coulomb collisions, but at different rates because the electrons are lighter than the ions. This causes an imbalance in the electron and ion temperatures that triggers energy exchange between them in order to reach temperature equilibrium. This electron-ion temperature relaxation is one of the key processes that must be modeled in order to accurately describe the temperature runaway (ignition) of a thermonuclear plasma.

The electron-ion temperature relaxation rates, i.e., the rate at which electrons and ions exchange their energy to equilibrate, were first calculated by Lev Landau and Lyman Spitzer over 70 years ago for classical plasmas with weak collisions. Since then, there have been several improvements proposed to account for the collective effects (e.g., screening, wave oscillations) inherent to plasmas, or the quantum nature of the electrons or the correlation effects in the particle motions. None of the models had been validated to sufficient accuracy for ICF conditions until now with the advent of plasma molecular dynamics (MD) simulations on sufficiently large-scale computers. We performed hundreds of MD simulations under a variety of physical and numerical conditions to test the most modern theories of temperature relaxation with sufficient numerical accuracy and convergence [1]. We found very good agreement with the most rigorous theory in the weakly coupled (gaseous) regime [2]. We extended the calculations to the correlated (liquid-like) regime where the theories are much more complicated. Both regimes must be understood because ICF capsules traverse these regimes as they become heated from solid-state plasma to the thermonuclear state. We successfully devised a compact model that includes self-consistently the effects of screening, electron degeneracy and correlation between electron and ions [3]. The model reproduces well our accurate MD data and joins the weakly and strongly coupled regime (see Fig. 1). We applied our model to dense hydrogen and could unravel the relative importance of quantum and correlation effects on the energy exchanges between electrons and ions. A complete formula is now being devised for the ICF design codes.

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[1] G. Dimonte, J. Daligault, *Phys. Rev. Lett.* **101,** 135001 (2008).
[2] L.S. Brown, D.L. Preston, R.L. Singleton, *Phys. Rep.* **410,** 237 (2005).
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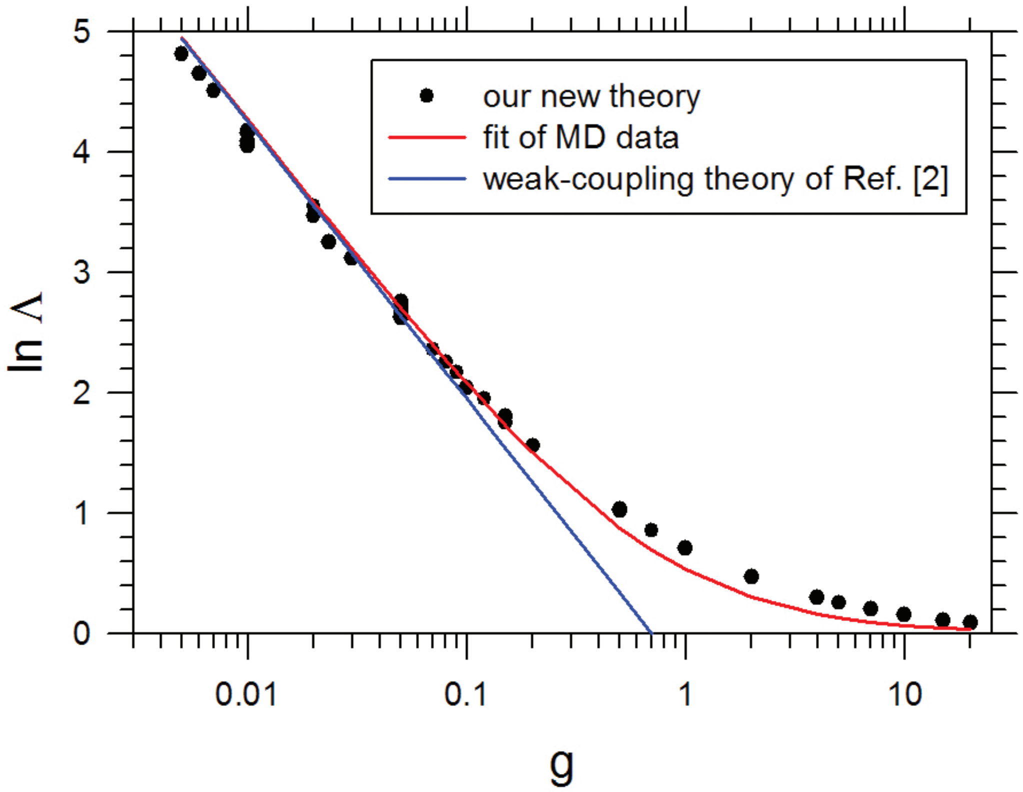

Fig. 1. We have calculated with MD simulations the temperature relaxation rate υ_{ei} between electrons (e) and ions (i) in a like-charge, classical hydrogen plasma over a wide range of plasma coupling parameter g (g = mean potential per particle/mean kinetic energy per particle). The rate υ_{ei} can generally be written as the product of a simple, universal energy transfer rate ν_0, times a dimensionless quantity lnΛ, the so-called Coulomb logarithm, which corrects for all the correlation and many-body effects arising in a plasma. The figure shows the Coulomb logarithm from various calculations as a function of the plasma coupling g. The red line is a simple fit to our MD simulations [1], the blue is the weak-coupling result of Ref.[2] and the dots are the results of our compact model Ref.[3].

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